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Research Institute of
Science and Technology
for Ceramics, *Faenza, Italy*

Development of UHTC-
Ultra-High-Temperature Ceramics
for aerospace and industrial applications

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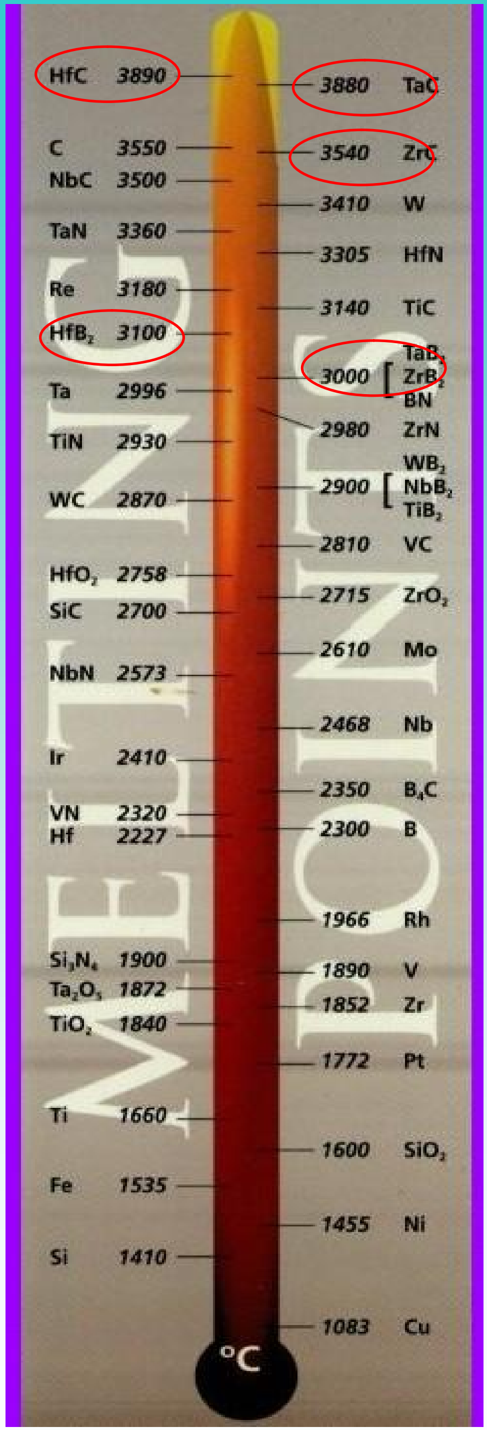
ISTEC Team on Structural Ceramics: about 10 researchers and technicians

i-techpartner FORUM- New materials , Valencia, Spain, March 5, 6 2009

Why UHTCôs ???



The design and production of new materials suitable to withstand high temperatures are nowadays stimulated by the increasing demand for applications:

- in the field of thermal protection systems,
  for several industrial sectors,
  for reausable atmospheric re-entry vehicles,
  for hypersonic flight vehicles
- As radiation resistant materials (for nuclear plants)
- Rocket propulsion.

Why Ceramics?

Abundant Ceramic Materials options with melting points **3000-4000°C**

Nitrides, borides , oxides, and ternary -borides, -carbides, -nitrides, -oxides of

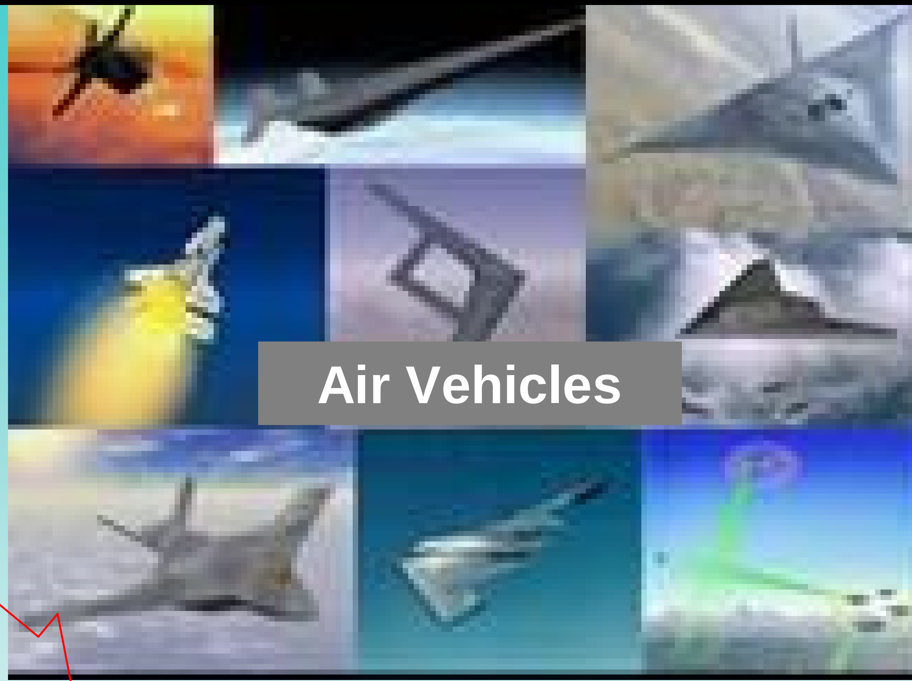
Hf, Nb, Ta, Re, Zré .

Compound	Melting T°C	Density g/cm^3
ZrB_2	3245	6.1
ZrC	3540	6.7
ZrN	2950	7.1
HfB_2	3380	11.2
HfC	3890	12.2
HfN	3305	13.8
TaC	3880	13.9

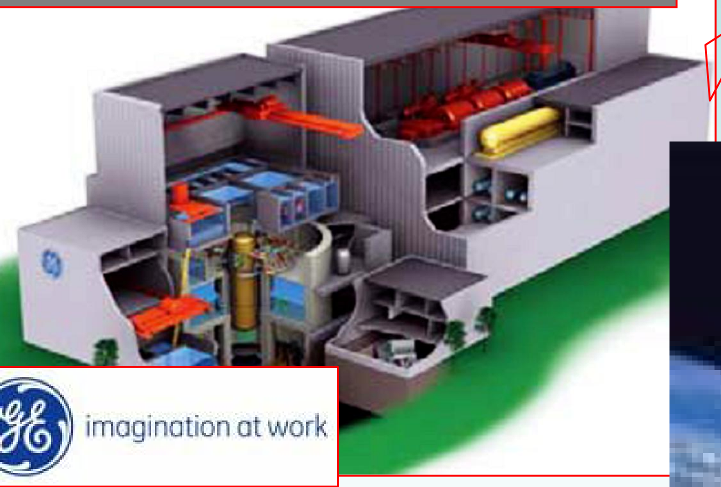
New Materials UHTC Ceramicsé

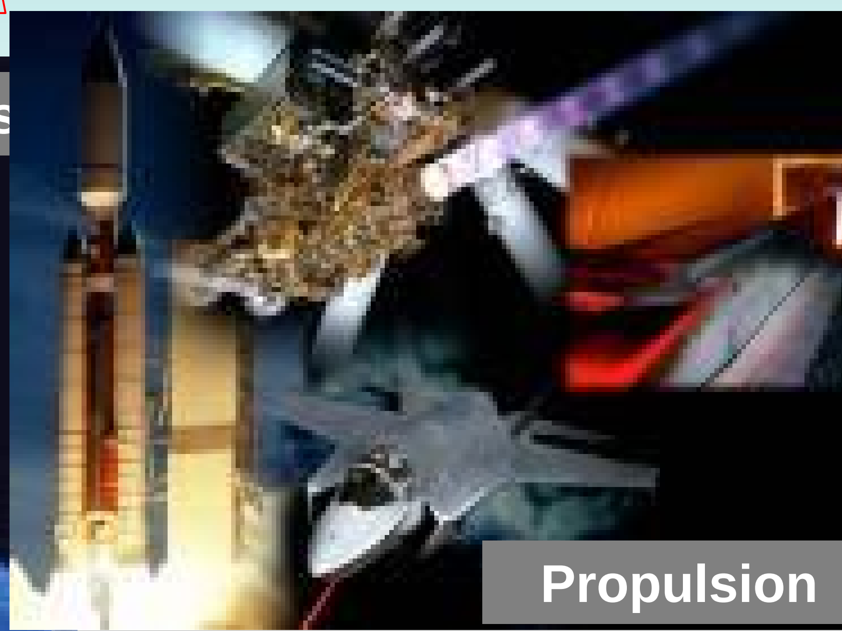
- The medium to long-term evolution of hypersonic vehicles,
- Re-entry and more general space transportation systems,
- Power for the Next Century

will be characterized by increasing utilization of advanced hot structures.



Leading technology in nuclear é





Air Force Res. Lab. USA

A Suite of Ceramic Materials

Materials	*Applications*	Component
Refractory Carbides	- Solid rocket nozzles, nuclear	
UHTC	-Hypersonic airframe, Propulsion systems, Hot Structures	
C/SiC Carbon/Silicon Carbide	- Liquid rocket and scramjet engines - Thermal protection	
SiC/SiC Silicon Carbide/ Silicon Carbide	- Turbine blades, vanes, combustors - Liquid rocket and scramjet engines	
Oxide/Oxide e.g. Alumina/Alumina	-Turbine combustors - Acreage thermal protection	
SiC/SiNC Silicon Carbide/Silicon Carbo-Nitride	-Turbine exhaust components	

3000-4000°C

2000°C

TEMPERATURE

Source : A. Katz, AFRL, Dayton, USA

AERO-SPACE

Launch and missiles

Required Higher temperatures to increase efficiency of propulsion systems

Payoff

High temperature, light weight structure and thermal protection systems for air and space

Superior performance / efficient urbine and rocket engines

Enhanced durability / lower life cycle cost

Range of dual use applications

Reentry

Required Higher temperature on external surfaces

[Above 2000 °C for sharp leading edge of atmospheric reentry vehicle

Above 3000 °C for planetary vehicles]

Objective:

Develop and demonstrate ceramic materials technology for space vehicle and on-orbit applications

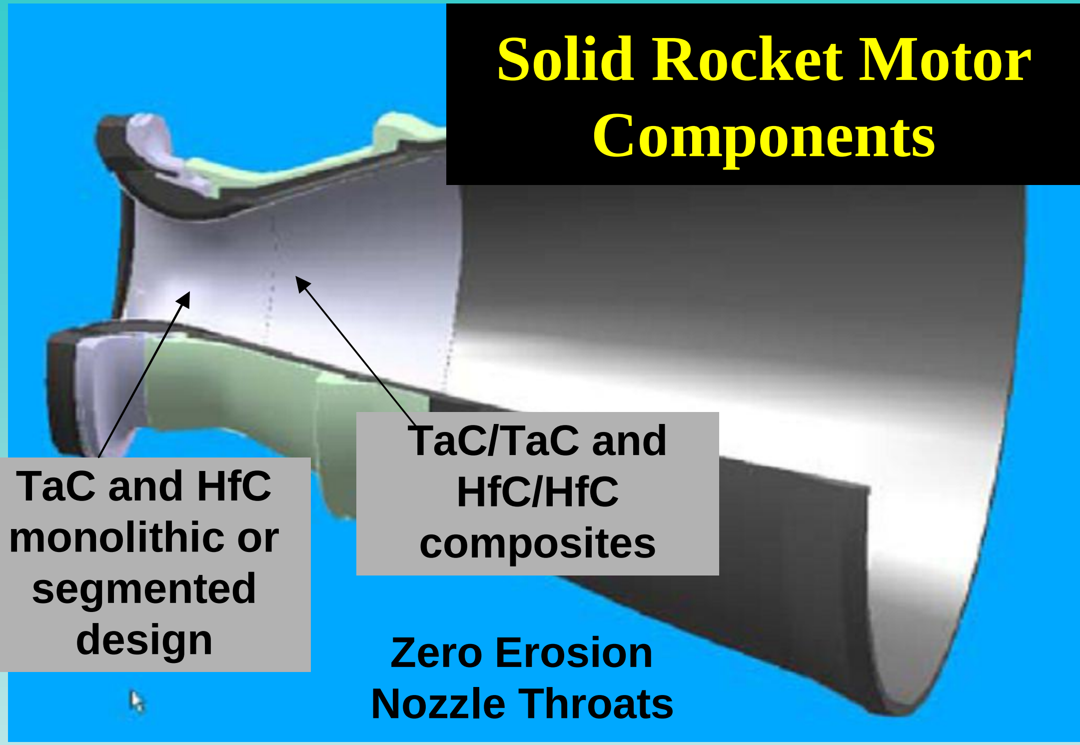
Å**Propulsion** -- Liquid and solid rocket engines, satellite, thrusters

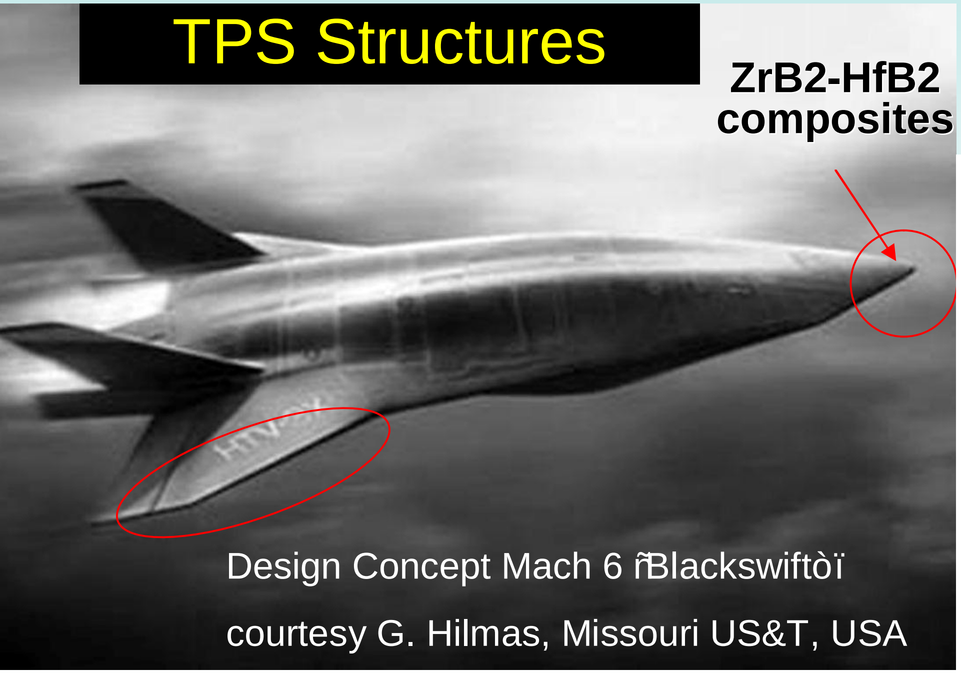
Å**Thermal Protection** -- Durable TPS and hot structure for reusable vehicles

Å**Hypersonics** ï Leading edges, cooled scramjet panels, struts, cowls, and nozzles

Air Vehicles
- Turbine Engines
- Hot Exhaust Structures
- Sustainment Brakes

Space Vehicles
- Rocket Propulsion
- TPS/Hot Structure
- Lightweight Mirrors



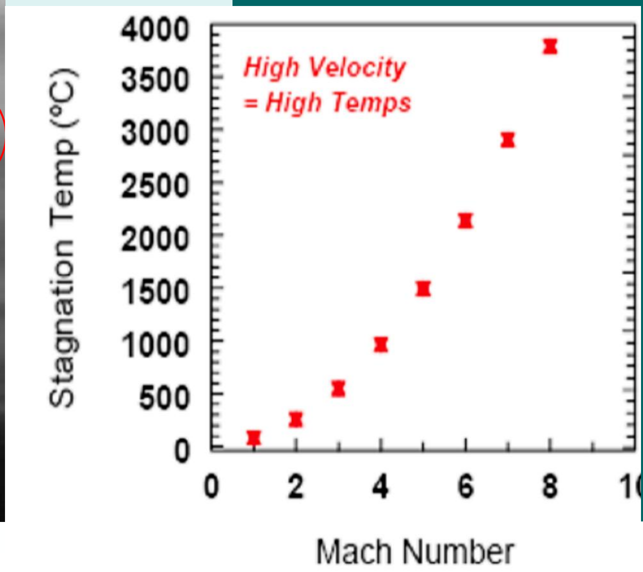


Aerospace Applications of UHTCs

Supersonic Flight,
Re-usable orbital vehicles,
New shuttle vehicle,
propulsion systems

Key issues:

Å Limited choice of ceramics
Å Processing-structure -property relationships
Å High T Corrosion



Next Generation (IV) Nuclear Plant

- Structural Composites Are Needed for Off-Normal, High-Temp Internals (>1200°C)
- Gas-Cooled Fast Reactor Needs Ceramics (very high T, fast neutron spectra)

UHTC Ceramics for Nuclear Applications

Pressure Vessel and fission product barrier

First Selection Trial for GFR Ceramics

T melt < 2000°, prohibitory neutronic absorption, too low thermal conductivity

	Matériau	T fusion T décomp (°C)
carbures	**SiC (α+β)**	**2972**
	ZrC	**3400**
	TiC	**3100**
	VC	**2810**
	TaC	3800
	WC	2900
	HfC	3800
nitrures	**ZrN**	**2952**
	TiN	**2950**
	AlN	**2227**
	~~TaN~~	~~3087~~
	~~Si_3N4~~	~~1827~~

	Matériau	T fusion T décomp (°C)
oxydes	Al_2O_3	2050
	MgO	2832
	$MgAl_2O_4$	2135
	ZrO_2	2370
	Y_2O_3	2427
	~~SiO_2~~	~~1470~~
siliciures	$MoSi_2$	2050
	$TaSi_2$	2200
	~~WSi_2~~	2165
	$TiSi_2$	1540
	$ZrSi_2$	1520
	$HfSi_2$	1750
	VSi_2	1660
	$CrSi_2$	1550

Source: Oak Ridge National Laboratory, USA

Objectives of ISTEC research on UHTCs

IMPROVE DENSIFICATION
Microstructure Control, Properties and performance

- **Problems**: **densification** of UHTCs requires pressure-assisted sintering procedures and T >~2000°C →**Coarse microstructures (10-60 μm) and residual porosity**

  toughness: monolithic ceramics are too brittle

  oxidation/corrosion: UHTCs are unstable in oxidizing atmosphere

- **Strategies**:

  - Advanced sintering techniques (SPS)

  - Conventional sintering techniques (HP, PLS) with effective sintering aids and/or reinforcing phases

  -Reaction sintering from precursors

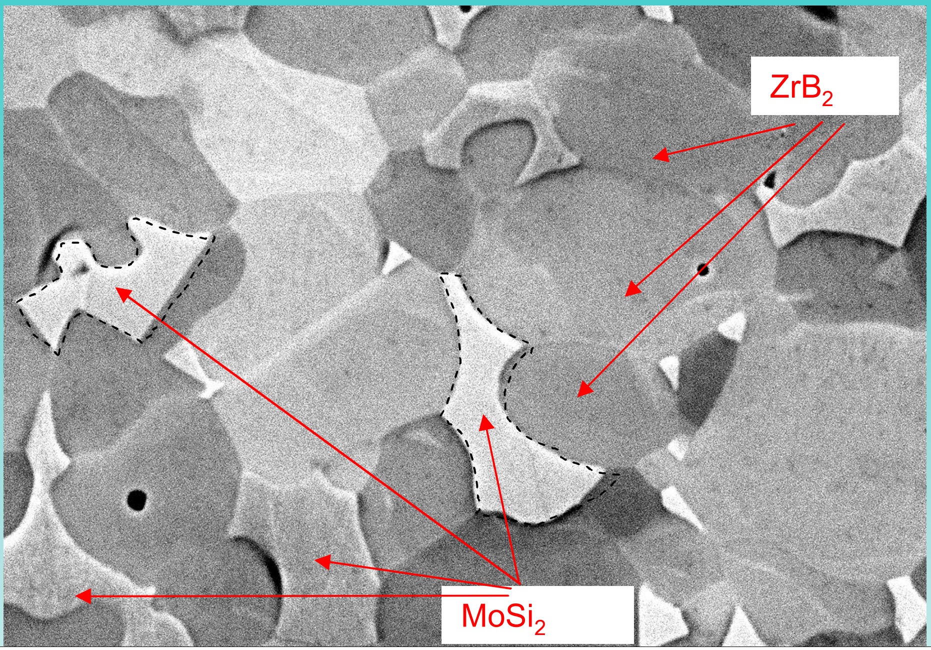
- **Systems investigated:**

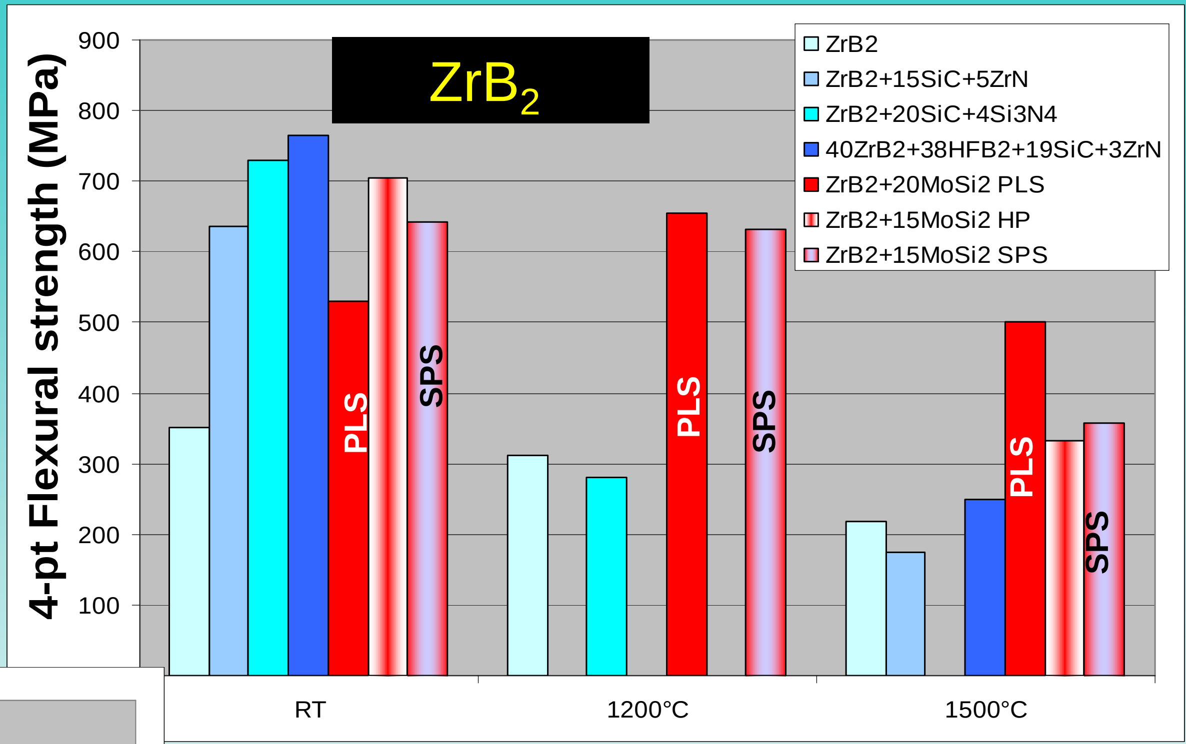
  - ZrB_2, HfB_2, HfC, ZrC, TaC

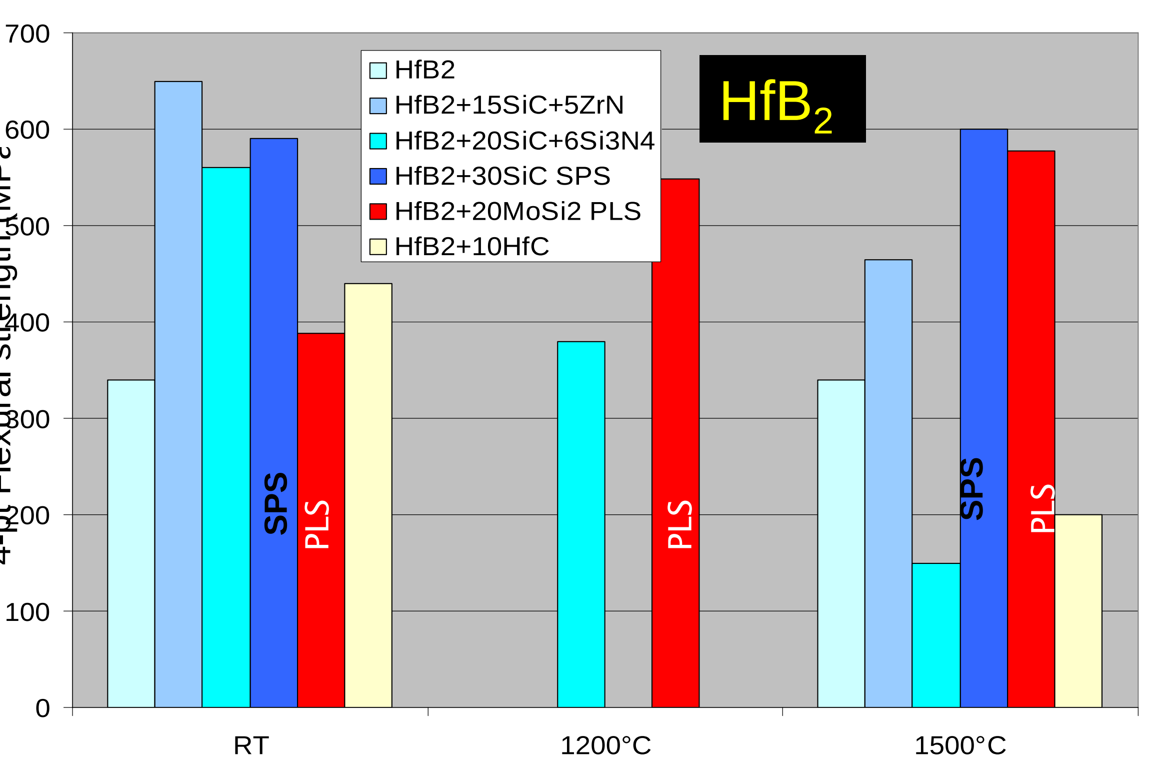
    +(SiC, $MoSi_2$, $TaSi_2$) as secondary phases (to improve toughness, strength, oxidation resistance)

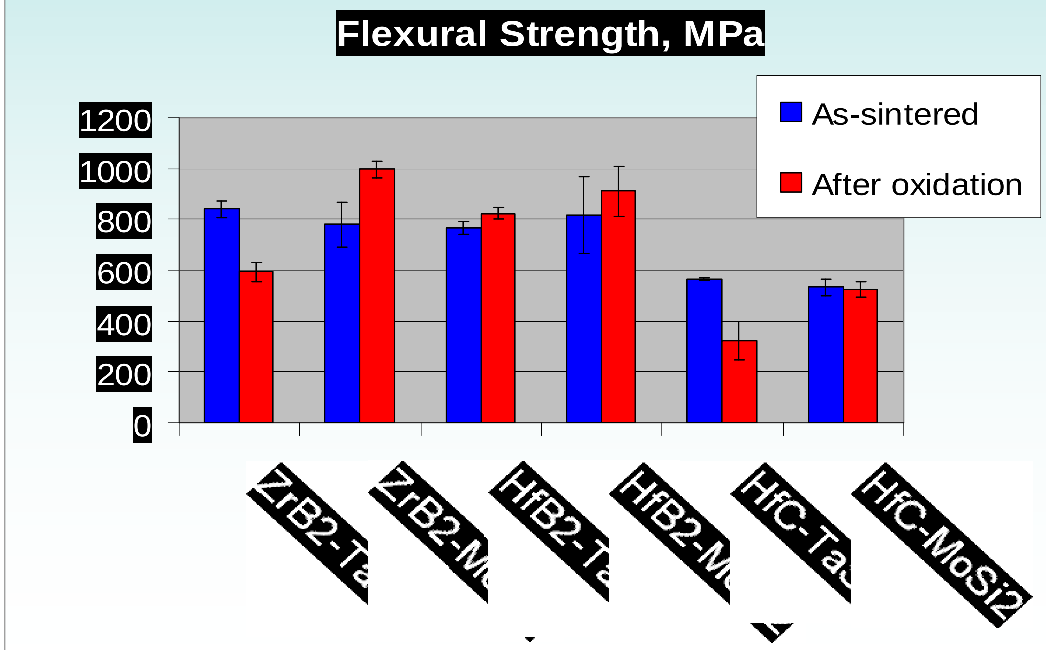
    + sintering aids (to improve sinterability)

UHTC: ZrB_2, ZrC, HfB_2, HfC, TaC, HfN….

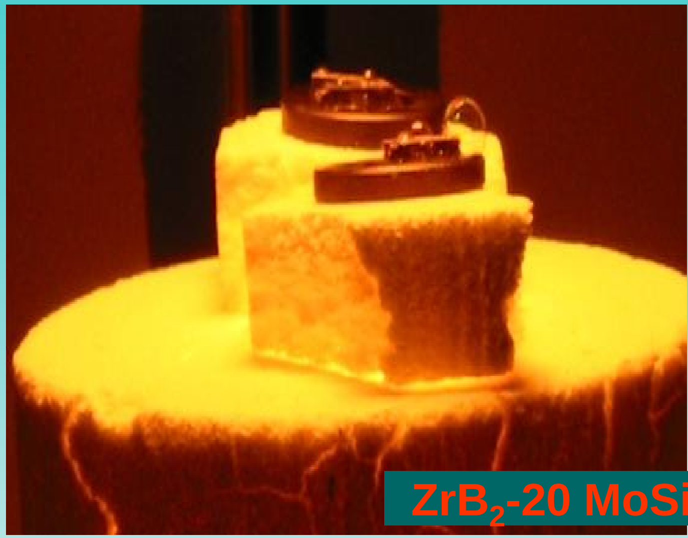


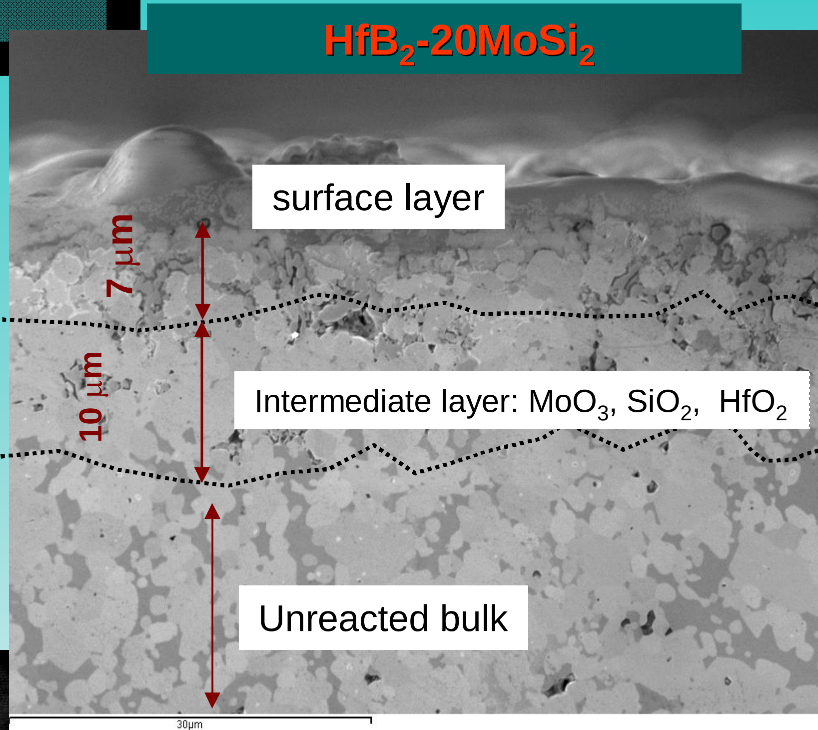


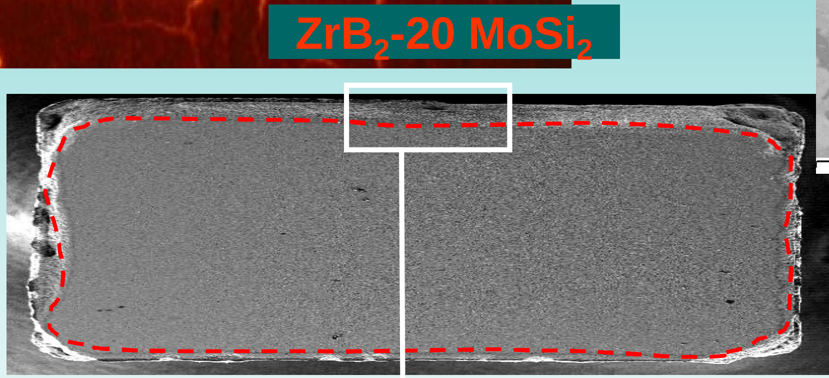


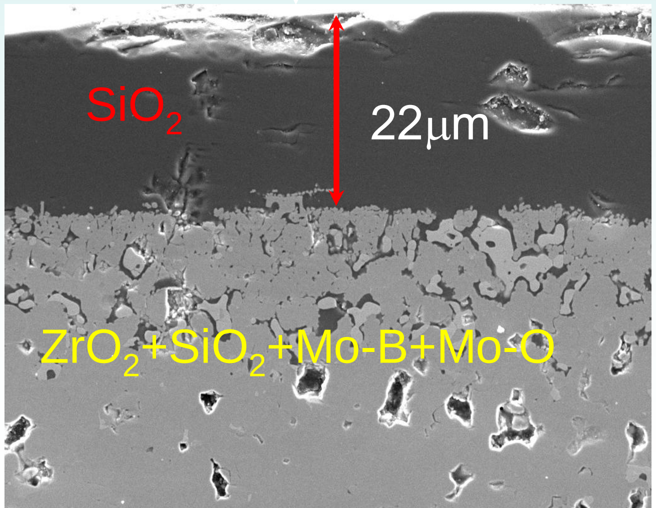


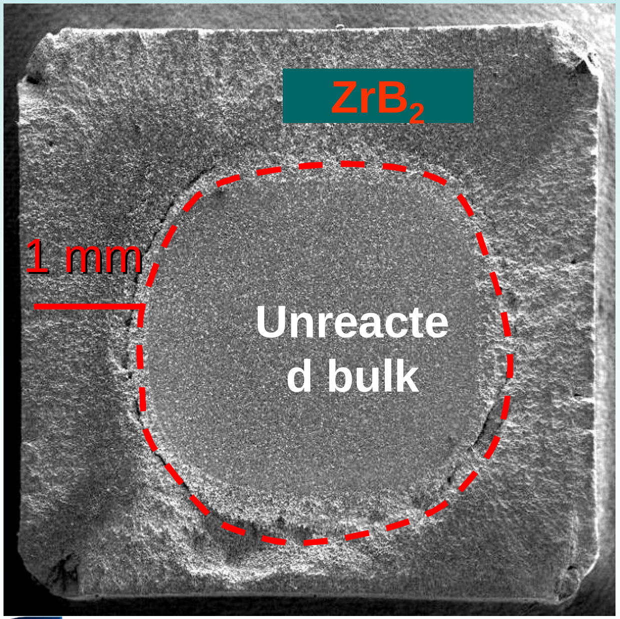
Oxidation tests 1600°C/15 min.

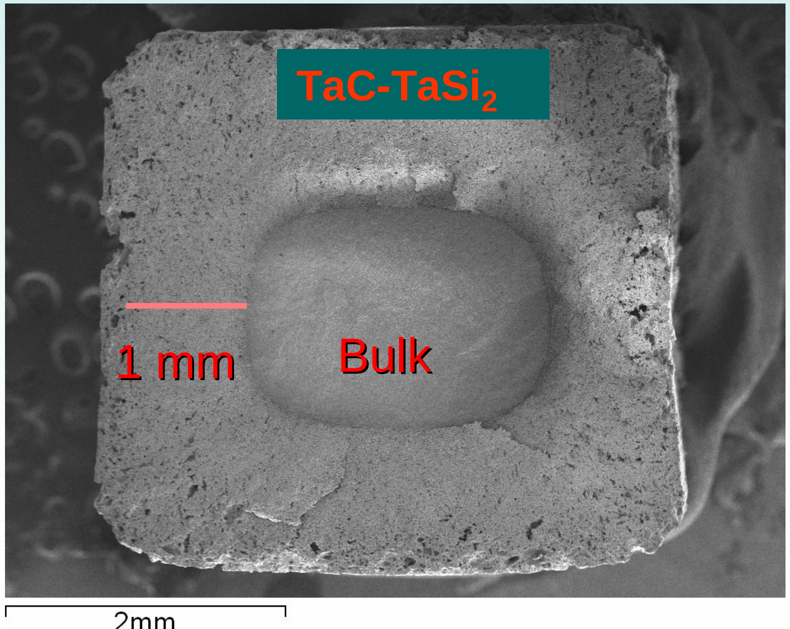












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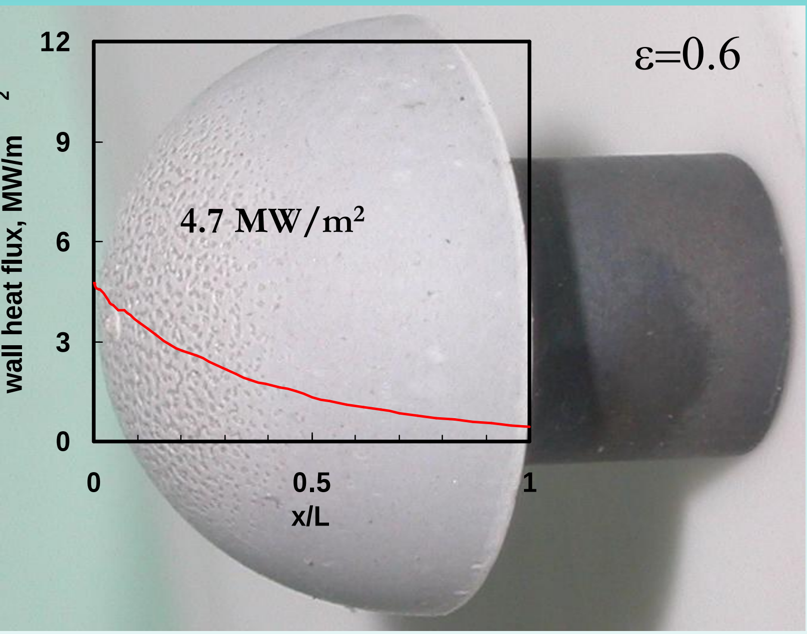
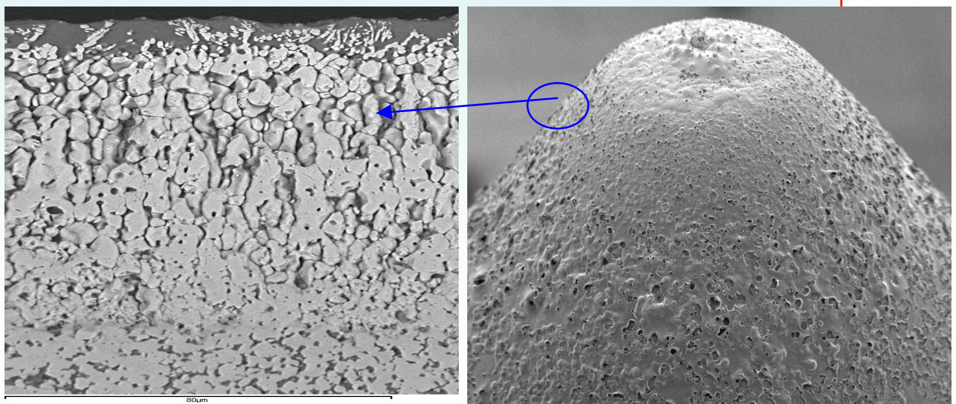
PLASMA JET test





Typical Reentry Peak Heating Rates (BOEING)

Heat Flux (kJ/m² s)	Radiation Equilibrium Surface Temperature °C	Candidate TPS Elements
11 to 110	400 to 1000	Metal standoff panels Ceramic tile
110 to 227	1000 to 1200	Tile Oxide-oxide panels
227 to 680	1200 to 1650	Tile CMC panels (SiC/SiC, C/Si/C)
680 to 1140	1650 to 1930	CMC, ablators, heat pipes
1140 to 1700	1930 to 2200	Ablators, active cooling

UHTCeramics

Source: Boeing, USA

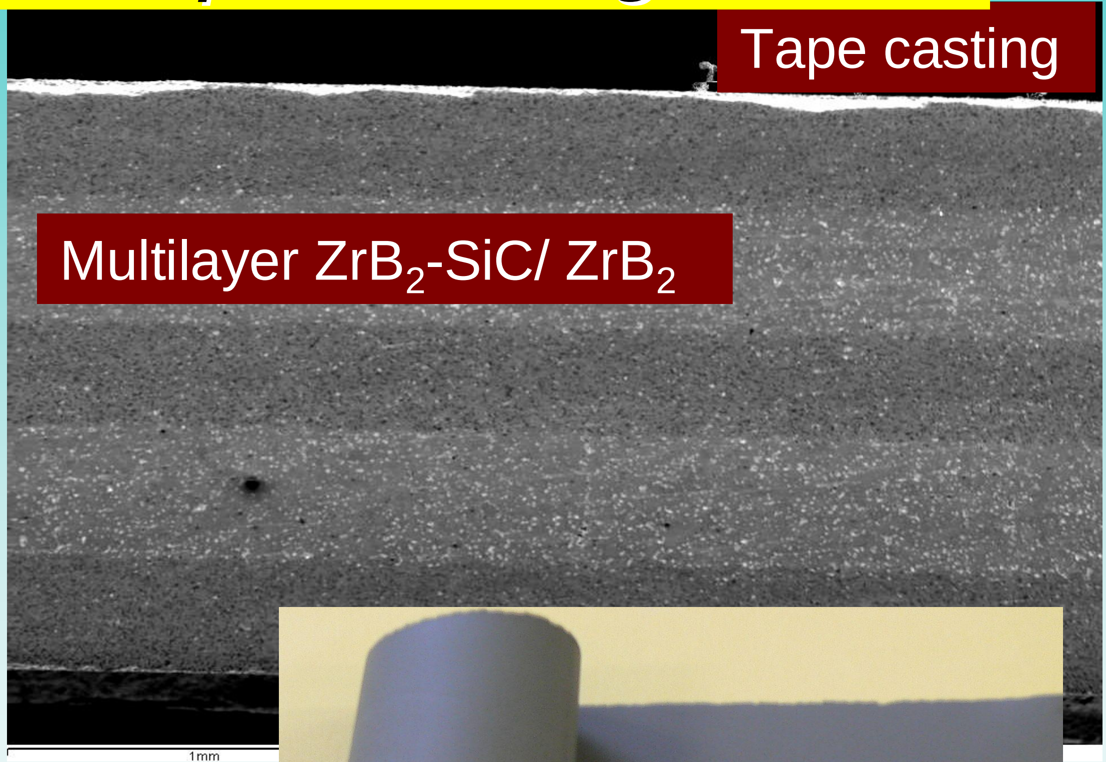
Production of complex shapes through electrical discharge machining

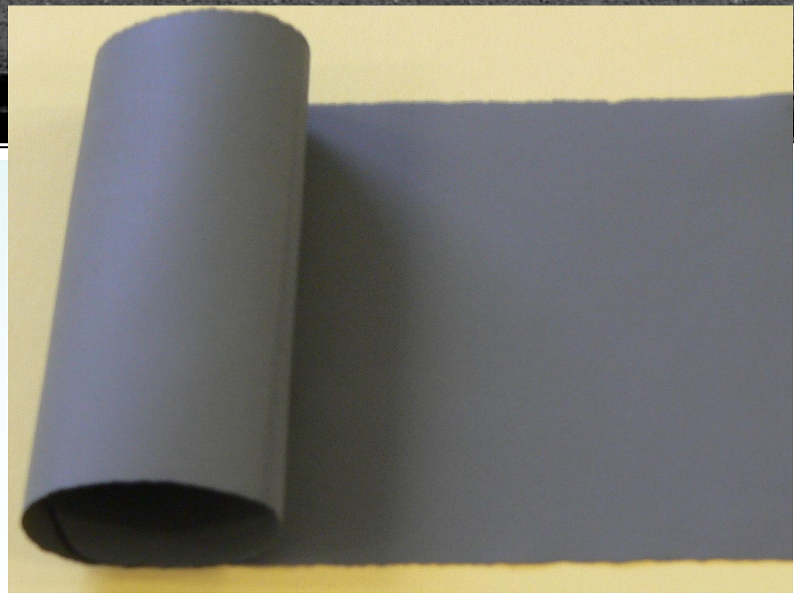
Production of complex shapes from conventional ceramic processing

Densification:

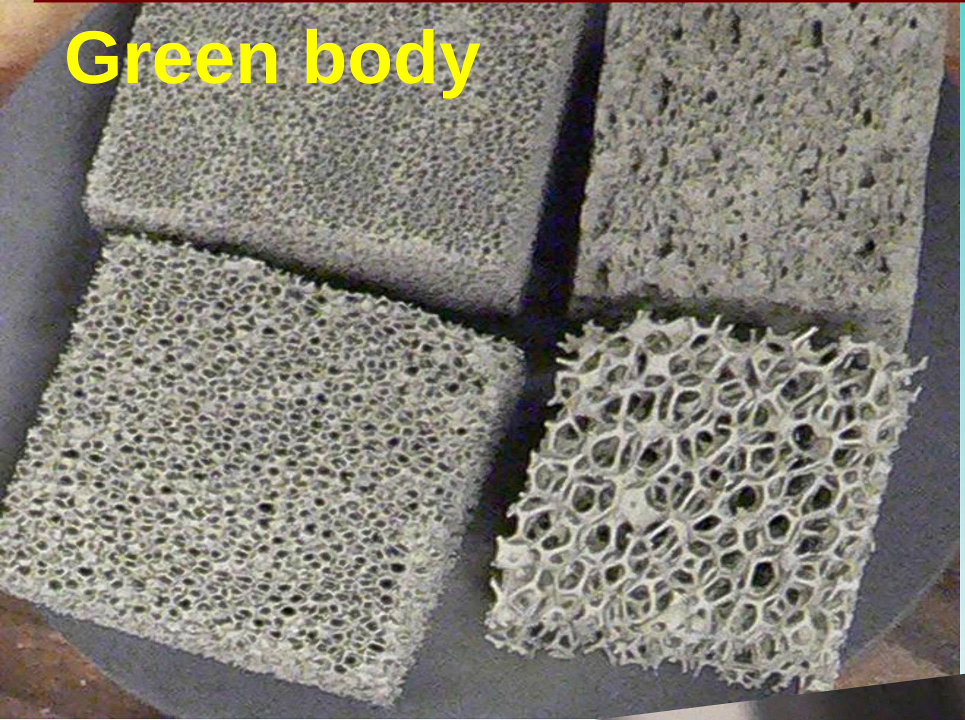
Pressureless sintering at 2150°,

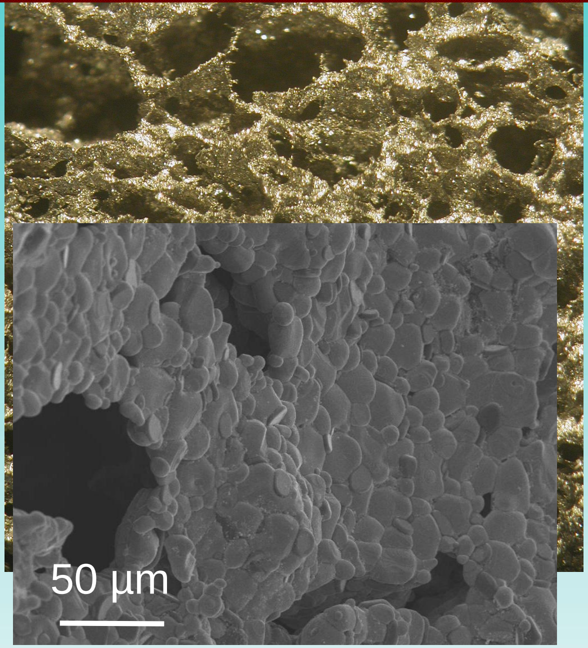
2h, argon

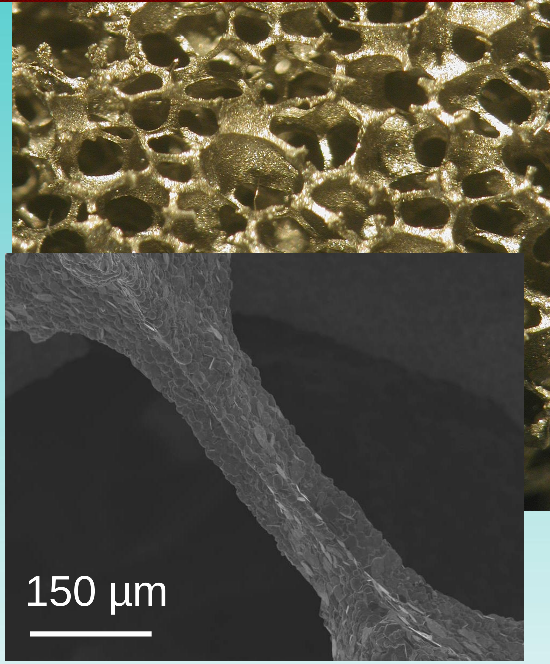




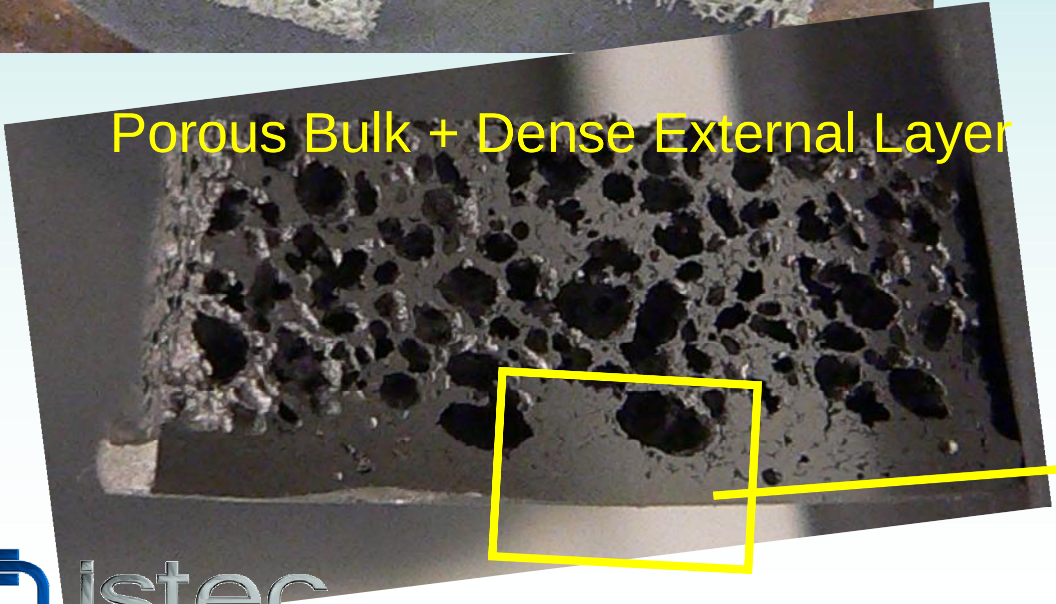
ZrB_2-based light-weight porous structures
Multilayers

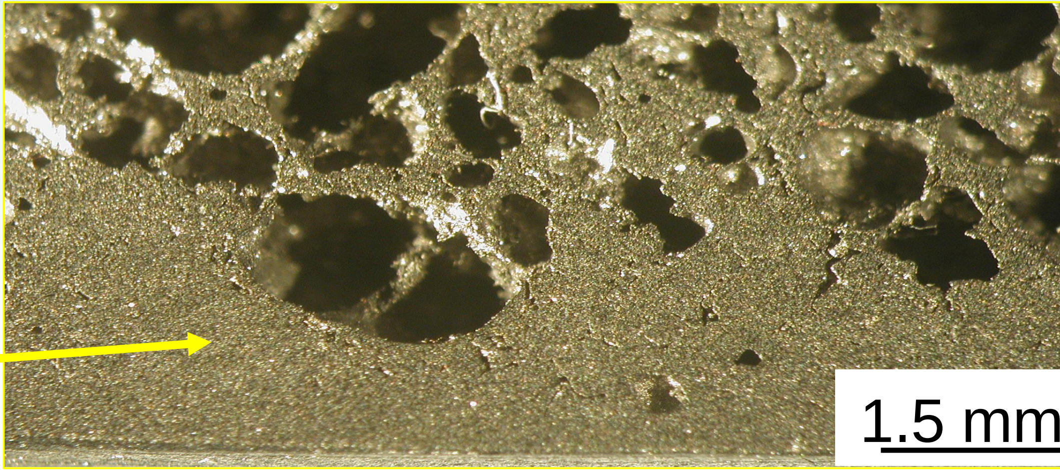






pressureless sintering at 2150°C, 2h, argon





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Know-how

Å The details about materials composition and properties

Å The details about the processing procedures

Å Key features determining the composition selection for specific applications

Å Assistance for the optimization of bulk and surface properties

Å Assistance for materials Characterization and properties evaluation

Production of

Å Samples for laboratory scale tests

Å Samples for bench tests

Å Prototypes of components or devices based on specific design (from the end-user).

What we offer

Advices about

Å Lay-out of a production line

ÅRaw materials producers

Å Plants - machinery - equipments

THANK YOU !!!!

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